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A microzonation study for coastal zone land-use planning: Kandira, Izmit (Turkey), case study

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Determination of the safe and risky areas in terms of soil properties is highly important in the planning of residential areas when considering natural hazard risks such as earthquake, landslide, etc. It is necessary to perform detailed soil investigations for safe constructions in most new settlement areas and also old cities which have a suitable topography. In this study, soil characteristics of coastal zone in Kandira district were investigated by in-situ and field survey data in order to prepare microzonation maps of the study area. The study area is covered by quaternary aged alluvium and upper cretaceous aged micritic limestones and located on the northern part of Izmit province and within a second-degree earthquake zone of Turkey. Determined Vs_{30} values and the soil amplifications are ranged from 77.8 m/s to 367.9 m/s and 1.67 to 4.12, respectively in the study area and SPT blow count values are less than 10 in the alluvium units. The obtained results in this study indicate that the west and east parts of the study area have better soil features. Considering the earthquake hazard of the study area, liquefaction analyses were performed and it was determined that some local areas in the alluvium have liquefaction risk.

[Keywords: Microzonation; Liquefaction; Land-use planning, Kandira]

Introduction

The land-use planning takes into account the condition of local soil properties in residential areas conveniently located for natural disasters. In particular, severe losses and damages due to the major earthquakes in recent years have been helped to develop the earthquake consciousness and the sensitivity to the measures to be taken against possible earthquakes. In assessing the earthquake risk for residential areas, local ground conditions play an important role besides the possibility and magnitude of the earthquake. During the earthquake movement, local ground conditions may also cause differences on structural damages. For this reason, detailed investigation of local ground conditions in areas with high earthquake risk is very important for the development of the earthquake resistant structure design.

Urban planning is identified short, medium and long term targets with data collection, analysis and synthesis methods for present states and anticipated solutions for future problems as well as describe applicable methods to achieve these goals[1,2]. The most basic constraints that can affect location choice in urban planning are the geological and physical constraints. These constraints are the topography, geological structure, climatic conditions, seismology, hydrogeological features, building materials, ground quality, mineralogical and geochemical features. Urban planning has an important place in the planning and mapping of geological environments of cities all over the world. There are many urban geology studies for planning purposes in some cities around the world[3,4,5,6,7,8,9,10,11].

One of the best methods contributing to the planning of settlement areas by exploring local ground conditions in detail is microzonation studies. There are many definitions in the literature about microzoning. Sharma and Kovaks[12] have described microzonation as a change in soil behavior effects in areas exposed to seismic activity. Nigg[13] described the purpose of microzonation as a subdivision of risky regions for the application of correct plans and policies in order to reduce the damages after an earthquake. Ansal et al.[14] have defined microzonation as a way of determining how the ground layers will behave during an earthquake and how earthquake forces affecting the structures will change within the study area, taking into consideration the earthquake characteristics that may be in a region. According to Finn et al.[15], microzonation is the procedure for the development of seismic hazard estimates for design taking into account the impact of local ground conditions. According to Sherif[16], the general purpose of microzonation is to provide the correct land use to minimize earthquake damage. Although the main objective of microzonation is to prevent future earthquake losses, it is known that many of these studies are designed to select the appropriate site for reconstruction after a damaging earthquake[17,18]. The first step in a microzonation study is the hazard analysis for possible ground motion considering the earthquake source and road characteristics. In the second stage, the behaviors of the ground layers are determined under the geotechnical ground conditions and determined ground motion. In the last stage, a zoning is established based on the results from the first two stages[19]. There are many microzonation studies carried out both in Turkey and in different parts of the world[20-30].

In this study, the soil characteristics of the coastal zone in Kandira district are aimed to present with microzonation maps. For this aim, the data belongs to the geological, geophysical and geotechnical studies applied in the study area were used. In order to evaluate the soil conditions of the study area, totally 21 drilling, 15 MASW (multi-channel analysis of surface waves), 10 microtremor studies data and many soil and rock samples laboratory tests results were taken into consideration in this study. In addition, liquefaction analyses were performed to determine whether the presence of liquefaction risk.

Liquefaction factor in microzonation studies

With the effect of dynamic stresses occurring as a result of an earthquake, the liquefaction event occurs as a consequence of increased water pressure and decreased effective stress in generally saturated granular soils. Many structures can be affected by settlement, overturn and ground failures due to liquefaction of such saturated granular soils. For this reason, determination of the factors causing liquefaction, the liquefaction potential in vulnerable areas and the prediction of possible damages are among the most important research topics in geotechnical earthquake engineering. The liquefaction potential depends on the geotechnical properties of the grounds, topography, seismicity, groundwater level and geological history[31]. As a result of researches on liquefaction, useful empirical methods based on experimental and probabilistic calculations have been developed to determine liquefaction potential[32]. Liquefaction potential can be determined in the laboratory by dynamic three-axis, dynamic cutting, shaking tests and by Standard Penetration Test (SPT), Cone Penetration Test (CPT) and seismic experiments in the field[33-44].

In literature, the most important study to investigate the liquefaction potential of soils has presented by Seed and Idriss[38] as a "simplified procedure". Seed and Idriss[38] have basically expressed the liquefaction potentials of the soils by two parameters. The first parameter is the ratio of cyclic stress (CSR) which indicates the level of cyclic loading that can be caused by the earthquake, and the second parameter is the rate of cyclic resistance (CRR) that indicates the resistance of the soil against the liquefaction. The ratio of cyclic stress generated during earthquakes (CSR) is defined as in Equation 1.

$$CSR = 0.65 \times \frac{a_{max}}{g} \times \frac{\sigma_v}{\sigma'_v} \times r_d \qquad \ldots (1)$$

Here is, a_{max}, the peak horizontal acceleration at the ground surface during the earthquake; g, gravitational acceleration; σ_v and σ'_v total and effective stress; r_d, stress reduction coefficient. The average values are used for the r_d depending on the depth in the Equation 2 in engineering applications.

$$r_d = \begin{cases} 1.0 - 0.00765z, z \leq 9.15 \text{ m} \\ 1.174 - 0.0267z, 9.15 < z \leq 23 \text{ m} \end{cases} \qquad \ldots (2)$$

In order to determine the rate of cyclic resistance (CRR), Youd et al. (2001) suggested the following equation;

$$CRR = \frac{1}{34-(N1)_{60}} + \frac{(N1)_{60}}{135} + \frac{50}{[10*(N1)_{60}+45]^2} - \frac{1}{200} \qquad \ldots (3)$$

Corrected SPT-N values used in the liquefaction analysis are suggested to be corrected as follows, taking into account the effect of fine grain ratio (FC) on liquefaction resistance;

$$N1_{60,CS} = \alpha + \beta N1_{60} \qquad \ldots (4)$$

$$\alpha = 0 \text{ and } \beta = 1 \text{ for FC} \leq \%\ 5 \qquad \ldots (5a)$$

$\alpha = \exp\left(1{,}76 - \frac{190}{FC^2}\right)$ and $\beta = \left[0{,}99 + \frac{FC}{1000}^{1{,}5}\right]$
for % 5 < FC < % 35 ... (5b)

$\alpha = 1$ and $\beta = 1, 2$ for FC ≥ %35 ... (5c)

Here is; α and β are fine grain ratio correction coefficients, CS is the correction coefficient.

The safety factor for the liquefaction risk is defined as FS (Equation 6). If the safety factor is less than 1, it means that the zone involves the risk of liquefaction, if the factor is greater than 1, it indicates that the zone does not involve the risk of liquefaction.

$$FS = \frac{CRR}{CSR} \quad \text{... (6)}$$

Geological and seism tectonic features of the study area

The study area is a coastal zone and located on the northern part of Izmit province. The general geological settings of the study area and its surroundings are given in Figure 1. The rocks belonging to the Silurian period show a wide spread in the southern parts of Sile district while they seem in a narrower area on the north-western side of Izmit province. The rocks of this period are mostly greywacke, arkose, sandstone and quartzite. Devonian period outcrops such as sandstone, limestone and greywacke have a narrow and limited area in the northern and north-western part of Izmit. Triassic rocks such as sandstone, limestones, dolomite,

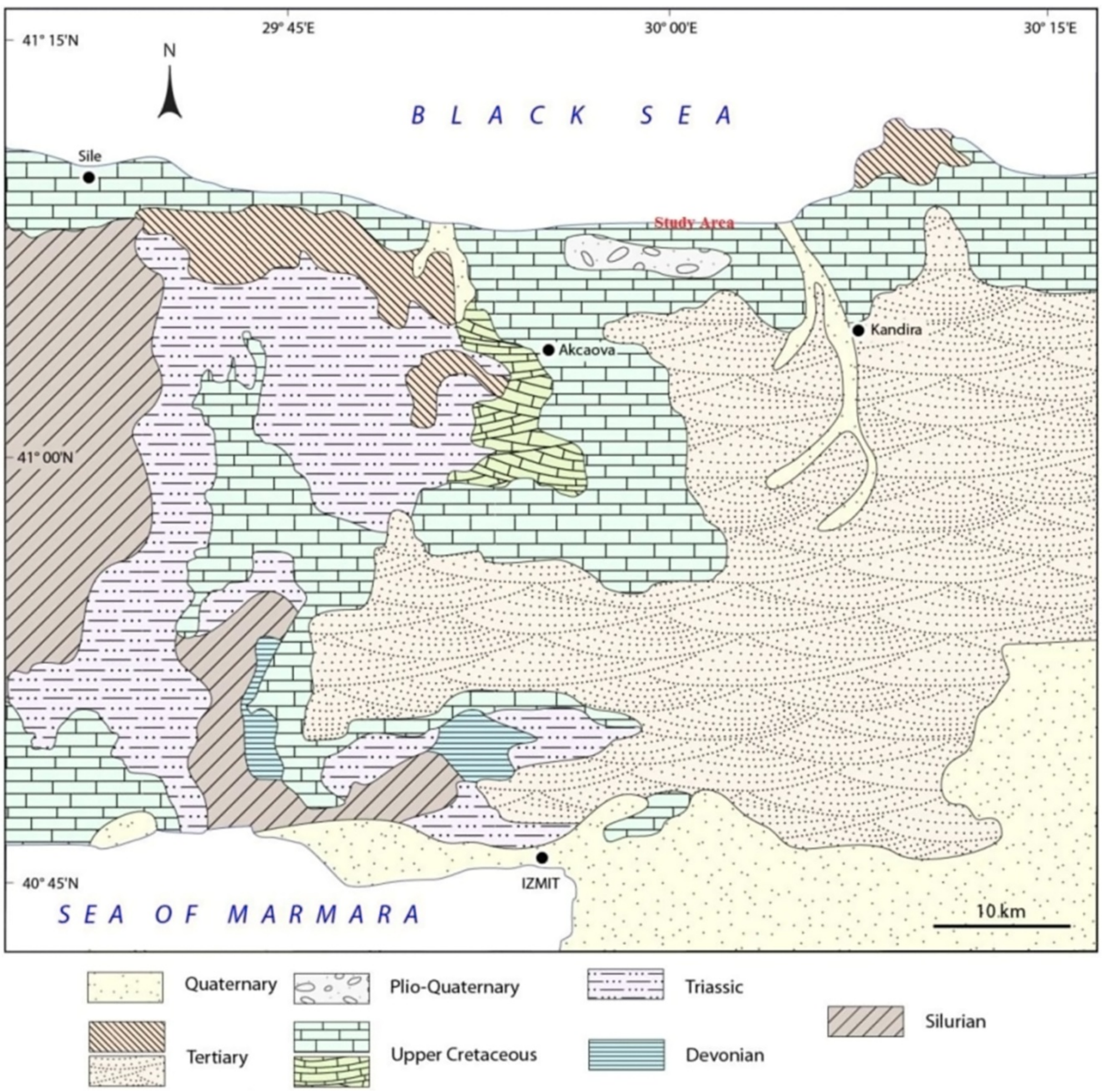

Fig. 1 — The geological settings of the study area and its surroundings

conglomerate, marl and shale are located on the north of Izmit Gulf. The Upper Cretaceous aged rocks with wide spread are seen in the western, northern and north-western part of Kandira district, around Şile district and north, northeast and far north of Izmit. The Akveren Formation is unconformably overlain to the Triassic rocks in this rock sequence and separated from others by a basaltic conglomerate. This formation contains beige-white limestones, friable and fragile clayey limestones and marl, conglomerate, volcanic intercalated sandstone, yellow micritic limestones[45,46].

There are two main geological unit are seen in the study area which are the quaternary aged alluvium and upper cretaceous aged micritic limestones belonging to Akveren formation. Quaternary aged alluvial deposits are seen in the surrounding area of the creeks and on the beach side of the study area (Fig. 2). The alluvial units are identified as brown clay, greenish gray clay, silt and sand. These units are the materials carried by the creeks. Other parts and sea - side slopes are composed of upper cretaceous aged Akveren formation; gray - beige colored micritic limestones and clayey limestones. These are usually regular and medium-bedded, and disruption product clay-silt units are visible at the shallow levels near the surface. Besides, there are some karstic cavities seen on the limestones. The slope in the study area is generally between 0 – 10 %, 10 – 40 % and has a sloping topography ranging from 40-70 % on the Black Sea margin in the northern part of the study area (Fig. 3).

The study area and its surroundings are under the influence of the North Anatolian Fault Zone (NAFZ) (Figure 4). The NAFZ is an active strike-slip fault in the world with well studied seismological-seismotectonic properties[47,48] and constitutes one of the most important tectonic elements of Turkey. Many devastating earthquakes occurred on the NAFZ during the historical and instrumental periods. There is a series of earthquakes on this fault zone, which occurred between 1939 and 1999 and migrated from east to west. A major earthquake occurred on August 17, 1999 around the town of Golcuk with a magnitude of Mw = 7.4, about 12 km south-east of the central Izmit province. A fracture exceeding 120 kilometers length was formed from the southwest of Duzce to the northwest of Yalova in the Sea of Marmara during this earthquake. The focal mechanism shows that the earthquake was developed as a right-lateral strike-slip fault. This solution also agrees with the general character of the NAFZ. Geological and geophysical studies following 17 August 1999 Izmit Earthquake have been focused on the location of the NAFZ system in the Sea of Marmara and the identification of the active parts that can produce earthquakes. According to these investigations, the 110 km section of the NAFZ within the Marmara Sea is more likely to produce an earthquake with a magnitude of 6.5 or even higher[49,50]. On the other hand, it is possible that the NAFZ segments will produce earthquakes of similar magnitudes in Hendek and Duzce in the east and Iznik in the south. This situation constitutes a

Fig. 2 — The geological map of the study area

Fig. 3 — The geological map of the study area

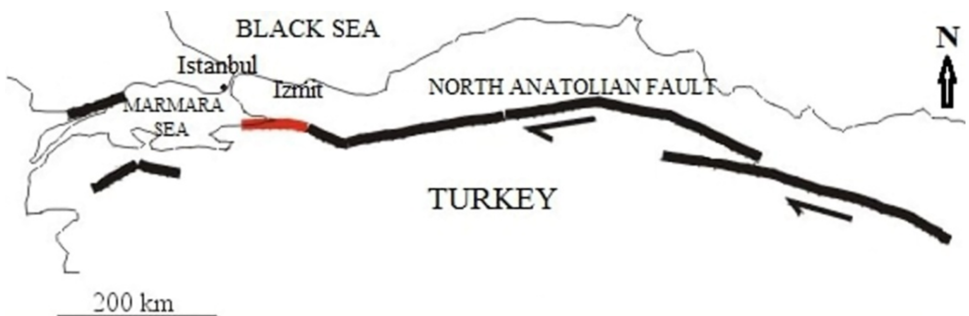

Fig. 4 — The location of the North Anatolian Fault Zone (NAFZ) affecting the study area

significant seismic hazard for the metropolitan city of Izmit like many large cities in the Marmara Region. For this reason, it has become extremely important to determine the dimensions of the seismic hazard, based on the principles of microzonation before such potential earthquakes occur.

Research results in the study area

Geophysical researches

In order to determine the geophysical characteristics of the study area multi-channel analysis of surface waves (MASW) and microtremor measurement results have been evaluated. The determination of S-velocity variations of underground layers is significant in terms of geotechnical engineering. In recent years, MASW method has been widely used in determining S-wave variations. Although the MASW method has similar measurement technique with seismic refraction method it is possible to obtain wave velocity information from deeper layers in MASW. The main objective of the MASW technique is to obtain the Rayleigh wave dispersion in which the phase velocity variations with frequency and to convert it to S-wave velocity and layer depth with inverse solution technique[51]. Especially the first 30 m depth shear wave velocity information is widely used for determination of the dynamic properties of soil in site assessments. At the same time, the local soil classes can be determined with Vs_{30} values. In this study, 15 MASW measurements data were used to determine the dynamic properties of soil in the shallow subsurface. The average of the S waves in the first 30 m depth (Vs_{30}) was determined between 77.8 m/s and

367.9 m/s in the study area. The local soil classes are generally identified as E and D according to these results[52]. The variation of the Vs_{30} values in the study area is shown in Figure 5.

The surface layers usually uncover the vibrations with natural resources (storm, sea waves) and artificial resources (plants, car, train, etc.)[53]. Recordable on the ground surface; at the same time, weak and low amplitude vibrations are called microtremor. The amplitudes of these vibrations range from 0.1 to 1 micron and the periods range from 0.05 to 2 sec. The predominant ground vibration period, soil amplification and the shear wave velocity (Vs) can be determined by microtremor method. The dominant periods and the soil amplifications were determined with 10 microtremor measurement results in the study area.

It is known that the soft ground layers magnify the amplitude of seismic waves during the earthquakes. All of the variations in seismic wave patterns in the ground layers are called "local ground effect". The local ground effect is known as soil amplification or soil response. To determine the possible soil amplifications caused by the earthquakes is of great importance for the earthquake-resistant design. If the soil amplifications are larger than 2, it indicate a soft ground[54]. The determined dominant periods ranged from 0.36 to 0.83 sec (Fig. 6) and the soil amplifications ranged from 1.67 to 4.12 in the study area (Fig. 7).

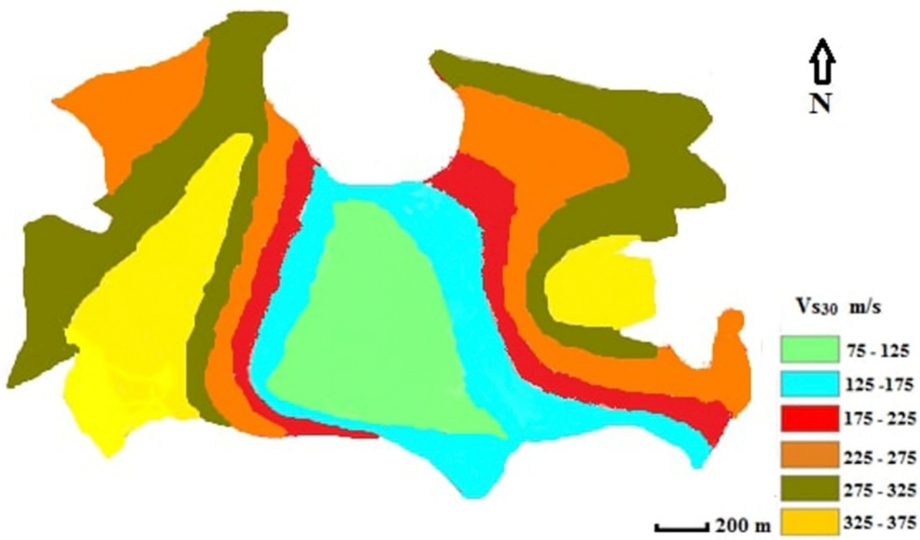

Fig. 5 — The variation of the Vs_{30} values in the study area

Fig. 6 — The variation of the dominant periods in the study area

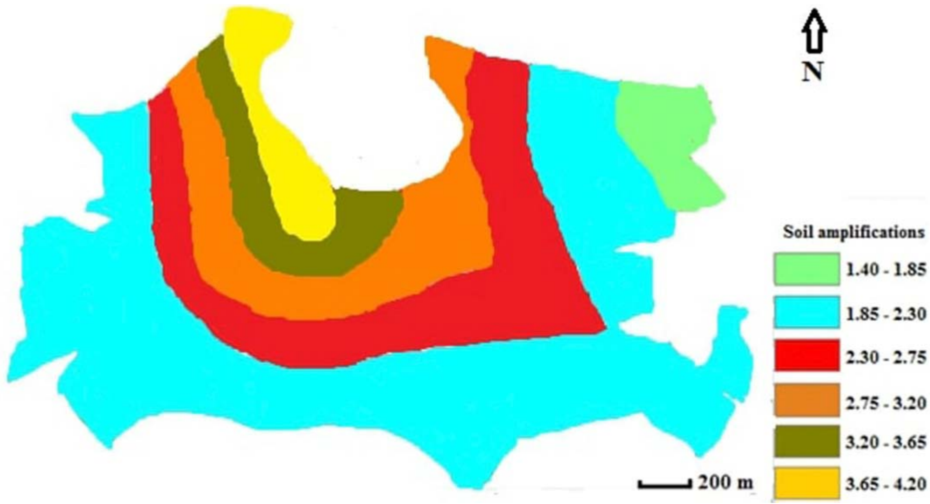

Fig. 7 — The variation of the soil amplifications in the study area *Geotechnical researches*

In order to determine the geotechnical characteristics of the study area, 21 drilling study results and laboratory samples test results obtained from these drillings have been used. The units cut in drilling wells whose depths are changing between 6 and 20 m are generally alluvium and limestones belonging to Akveren formation with weathering product clayey levels. The maximum alluvial thickness was determined to be 18.30 m. Generally the fine grained soils dominate the area considering the laboratory results of the soil samples taken from the study area. The soil classes are predominantly determined as high and low plasticity clay (CH - CL), however, high and low plasticity silt (MH - ML) and silty sands (SM) are also observed in some different depths according to USCS standards[55]. The clay units of alluvium are greenish brown in color at the surface and greenish gray at the bottom and the Plasticity Indexes (PI) ranged from 10 to 48. The color of the Akveren Formation clay is reddish brown and the Plasticity Indexes (PI) are ranged from 5 to 51. The results of triaxial compression tests on undisturbed samples are given in Table 1.

The SPT blow count values determined during the drillings are less than 10 in the alluvium units and generally changed between 20 and 50 in the Akveren Formation. The limestones of the Akveren Formation are gray beige in color in the study area. The RQD values are ranged from 0 to 92 and the rock qualities are defined as very poor - poor - moderate – good[56]. The results of Point Load Tests[57] on samples of limestones are given on Table 2. The strength values are range from 8.8 to 34.6 kg / cm^2 and these are defined as very low - low - medium strength[58].

Table 1 — Triaxial Compression Tests results of the undisturbed samples

Drilling Number	Depth (m)	c kg/cm^2	(Φ^0)	Formation
SK-1	2.50	0.5	2	Alluvium
SK-4	2.50	0.75	3	Alluvium
SK-5	2.50	0.29	2	Alluvium
SK-6	2.50	0.78	4	Alluvium
SK-7	2.50	0.23	2	Alluvium
SK-10	3.00	0.26	2	Akveren Formation
SK-14	2.50	1.41	3	Akveren Formation
SK-19	2.50	1.38	3	Akveren Formation

Table 2 — Point Load Tests results of the rock samples

Drilling Number	Depth (m)	Point Load $Is_{(50)}$ kg/cm^2	Drilling Number	Depth (m)	Point Load $Is_{(50)}$ kg/cm^2
SK-2	19.5	30.5	SK-15	7.4	17.8
SK-4	3.3	27.1	SK-15	8.5	31.2
SK-4	5.8	30.5	SK-16	13.1	21.1
SK-4	6.3	26.9	SK-16	15.2	23.3
SK-6	16.3	20.8	SK-18	9.2	17.5
SK-6	17.4	20.3	SK-18	10.5	8.8
SK-6	18.9	13.7	SK-20	13	8.8
SK-7	12.7	29.9	SK-20	14.8	10.5
SK-7	13.5	34.2	SK-21	10.4	34.6
SK-7	14.2	30.8	SK-21	11.8	27.5
SK-8	11.5	30.7	SK-21	12.9	23.9

Liquefaction risk assessment

In order to determine the liquefaction risk of the study area, liquefaction analyses were carried out for sandy soil layers in the alluvium. The procedure proposed by Youd et al.[44] was preferred for these analyses. The SPT-N blow counts, fine grain ratios (FC) and groundwater depths which determined during the in-situ and laboratory tests were used in related equations as given in "Liquefaction factor in microzonation studies" section in this paper. Due to its proximity to the North Anatolian Fault Zone (NAFZ), the study area is vulnerable to earthquake hazard. Therefore, the earthquake magnitude (Mw) and peak ground acceleration (a_{max}) were selected as Mw = 7.5 and 0,4 g, respectively during the liquefaction analyses. Only the first 10 m depth and the depths that have low SPT blow counts were taken into account for the analyses.

The safety factor does not directly allow for a relative assessment of large areas and the preparation of liquefaction maps in terms of liquefaction potential. With this in mind, Iwasaki et al.[59] proposed a parameter called "liquefaction potential index" which include the safety factor as well. Iwasaki et al. [59] proposed the following equations (Eq 7 and Eq 8a to Eq 8d) for the calculation of the liquefaction index.

$$LI = \int_0^{20} F(z)W(z)dz \quad \ldots (7)$$

$$FL<1{,}0 \text{ for; } F(z)=1-FL \quad \ldots (8a)$$

$$FL \geq 1{,}0 \text{ for; } F(z)=0 \quad \ldots (8b)$$

$$z<20 \text{ for; } W(z)=10-0{,}5z \quad \ldots (8c)$$

$$z>20 \text{ for; } W(z)=0 \quad \ldots (8d)$$

Here; (LI) is the liquefaction index, (z) is depth from the surface to the midpoint of the soil layer (m) and (FL) is the safety factor against liquefaction. In grading of the liquefaction potential of the soils the liquefaction indexes calculated according to the Iwasaki et al.[59] can be classified as in Table 3.

In this paper, the liquefaction indexes were determined using the liquefaction analysis results for the identified points in the study area and are given in Table 4. The liquefaction risk map generated using the liquefaction index values obtained for the study area is also shown in Figure 8.

Table 3— Liquefaction risk ratios according to liquefaction potential index (LI) (Iwasaki et al. 1982)

Liquefaction Index (LI)	Liquefaction Risk
0	Very Low
0< LI <5	Low
5< LI <15	High
15> LI	Very High

Table 4 — Liquefaction indexes calculated for the study area.

Drilling Number	Depth (m)	Liquefaction factor (FL)	Liquefaction Index (LI)	Liquefaction Risk
1	5.20	0.31	5.09	High
1	9.20	0.69	2.51	Low
2	7.70	0.75	2.20	Low
2	9.20	0.40	4.81	Low
3	3.70	0.67	0.79	Low
3	10	1.70	0	Very Low
5	3.20	1.10	0	Very Low
5	10.20	0.64	3.67	Low
6	4.70	0.53	5.38	High
6	10.20	0.57	3.00	Low
7	9.20	040	4.80	Low
9	6.20	0.36	6.55	High

Fig. 8 — Liquefaction risk map of the study area Discussion and Conclusion

Fig. 9 — Final hazard map of the study area

Discussion and Conclusion

In this study, the geological, geophysical and geotechnical research results were used together to determine the settlement suitability of a coastal strip of Kandira district, Izmit province within microzonation principles. According to the results, two different geological units which are the quaternary aged alluvium and upper cretaceous aged limestones observed in the study area. *In situ* and laboratory experimental results evaluated in this study were used to prepare the microzonation maps (Figs. 5, 6, 7, 8, 9) representing the soil properties for the study area.

As seen on the final hazard map (Fig. 9), it is clear that the northeast and northwest parts covered by limestones belonging to Akveren Formation have much better engineering parameters considering the mechanical and dynamic properties of the soils in the study area. The other parts controlled by typical alluvium character. The alluvium has high plastic clays and soft form sands according to the experimental results. In the alluvium where the SPT values are around 10 and lower in some parts, the Vs_{30} values generally ranged between 100 - 250 m/s and the soil amplifications ranged between 2 - 4. Moreover, liquefaction risk has been determined in some regions of the alluvium. Some of the limestone parts belonging to the Akveren Formation in the northern part of the study area have a slope of more than 40%. It was observed some karstic cavities and rock falls along the slope due to its thin layered structure. These areas are not suitable for settlement and excluded from the prepared microzonation maps representing the study area.

In-situ and field survey study results are generally consistent with each other in the study area. The soft and stiff areas are also compatible in terms of soil properties in prepared microzonation maps. All the results and microzonation maps indicated that it may occur structural problems arising from the soil properties during a possible earthquake in the study area. Considering the earthquake hazard of the study area and this study outputs, it is inevitable to take necessary measures while going to construction.

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